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None

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UK CL (Edition K) H1Q QEC QEJ QEX QKJ
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(54) Frequency selective structure

(57) The structure (10) incorporates first and second conducting layers (12,16) and an interleaving dielectric layer (14). The conducting layers (12,16) have periodically arranged slots (18,20) through their thickness. The layers are arranged such that the slots (18,20) do not overlap when viewed perpendicular to the layers (12,14,16). The thickness of the dielectric layer (14) is very much smaller than a wavelength of radiation at the transmission frequency of the structure. Consequently, significant evanescent coupling occurs between the two conducting layers (12,16). The frequency selective structure (10) exhibits radiation transmission over a narrow bandwidth, and transmission characteristics are relatively unaffected by incidence angle or polarization.

Fig.1a.

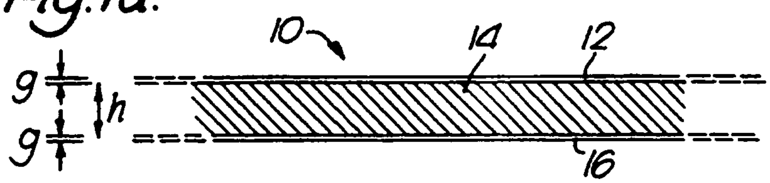

Fig.1b.

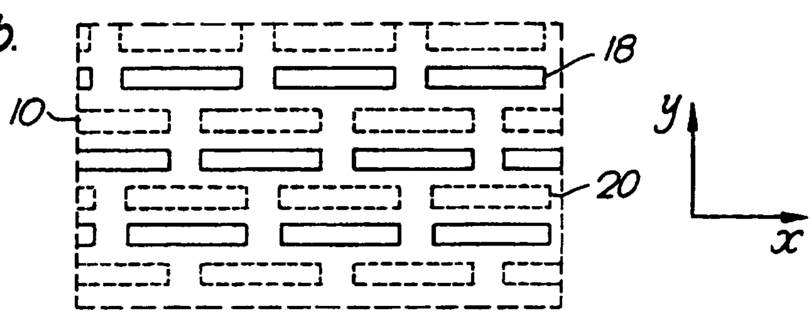

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Fig.1a.

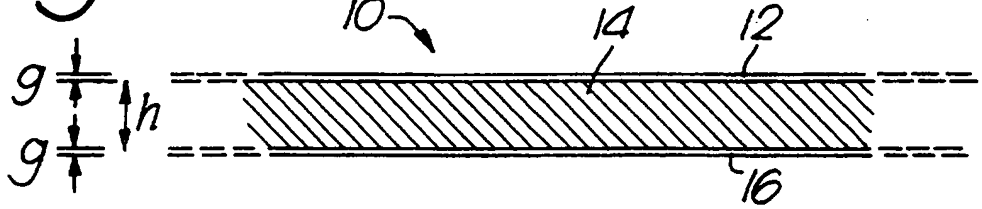


Fig.1b.

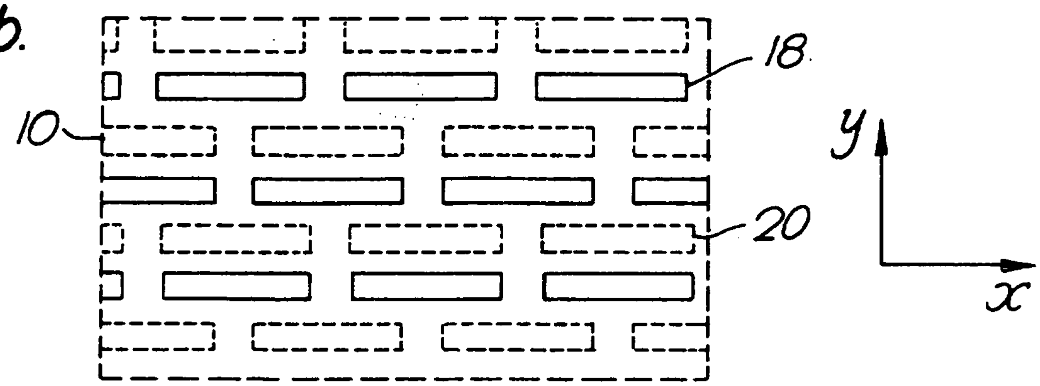


Fig.1c.

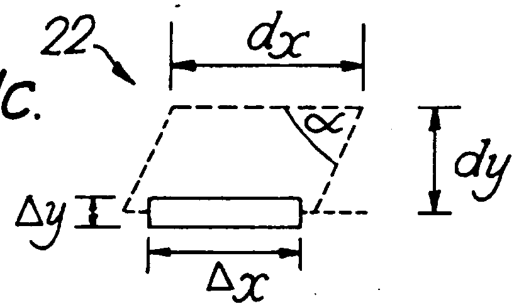


Fig.2.

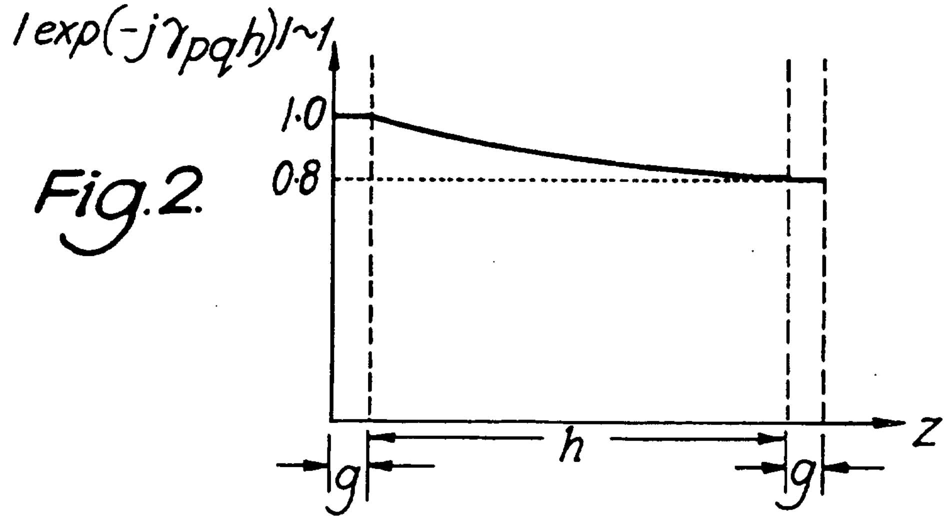


Fig.3.

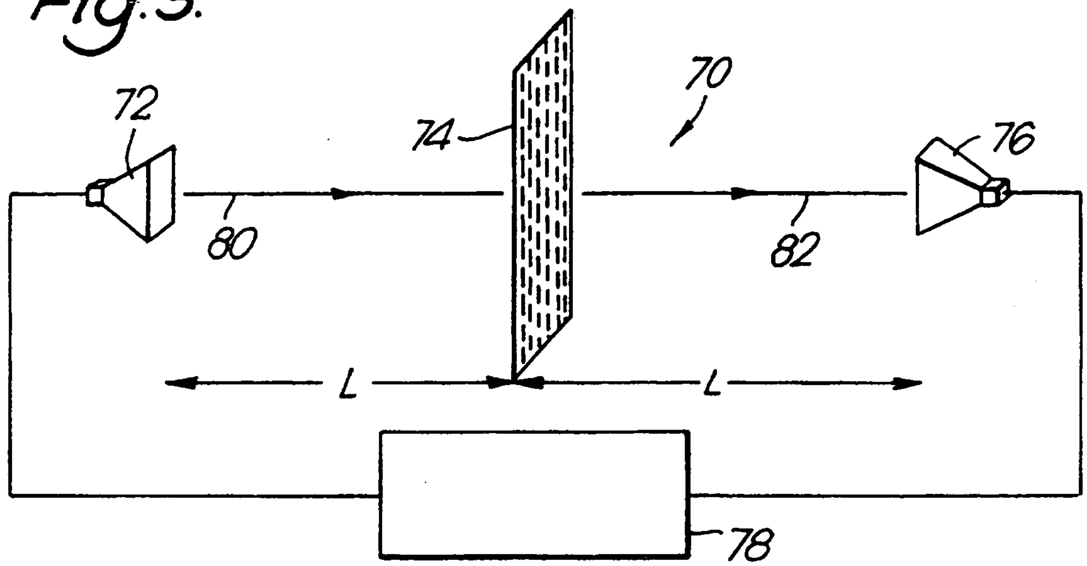


Fig.9.

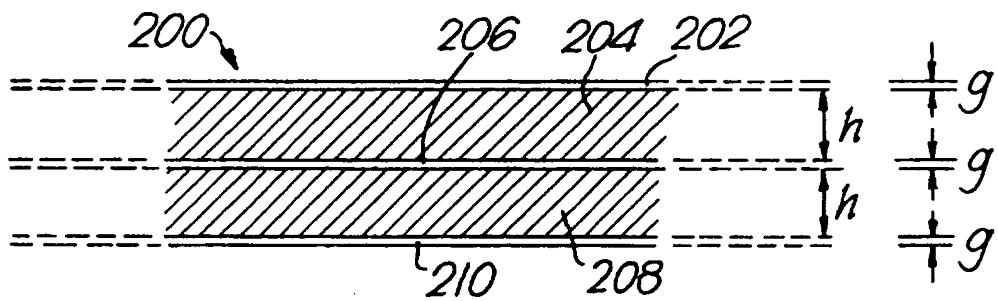


Fig.10.

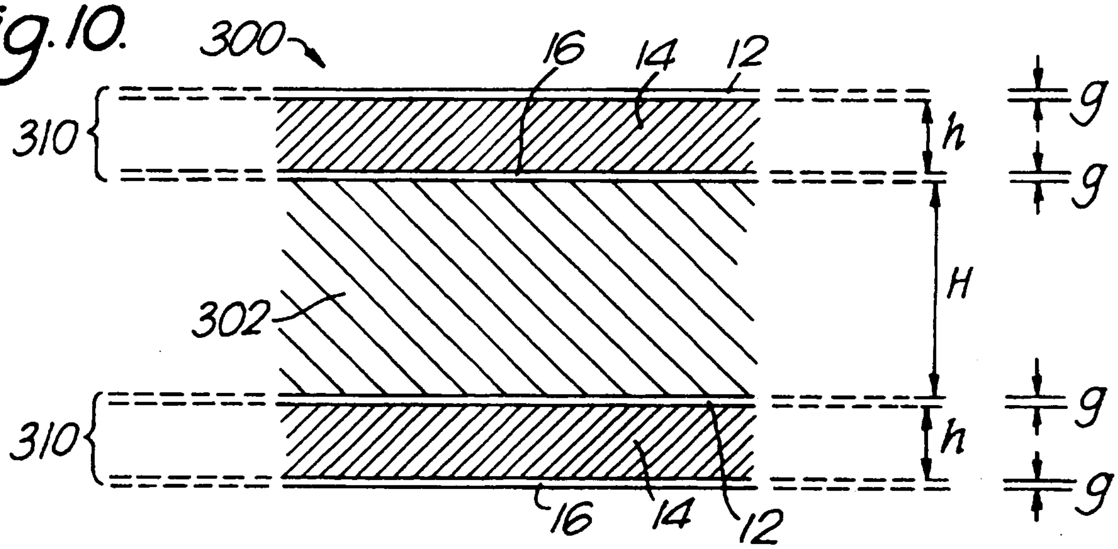


Fig. 4a.

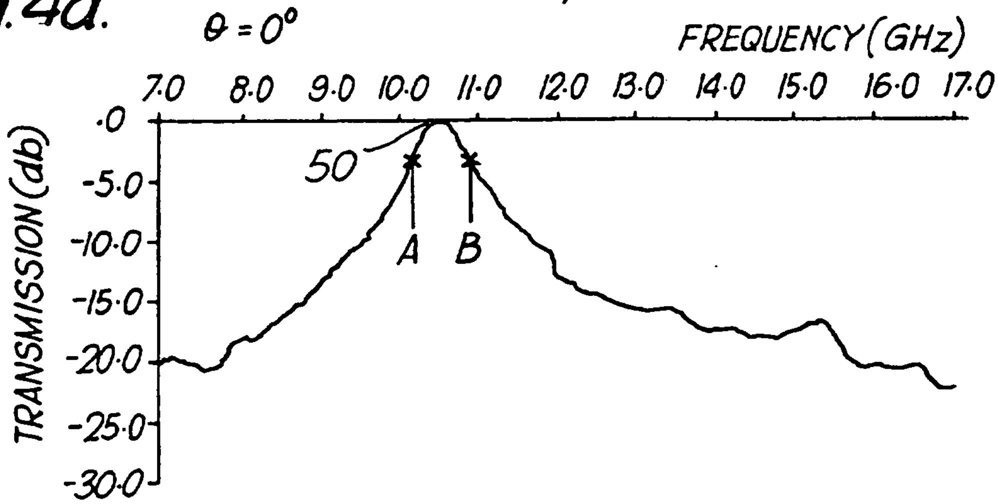


Fig. 4b.

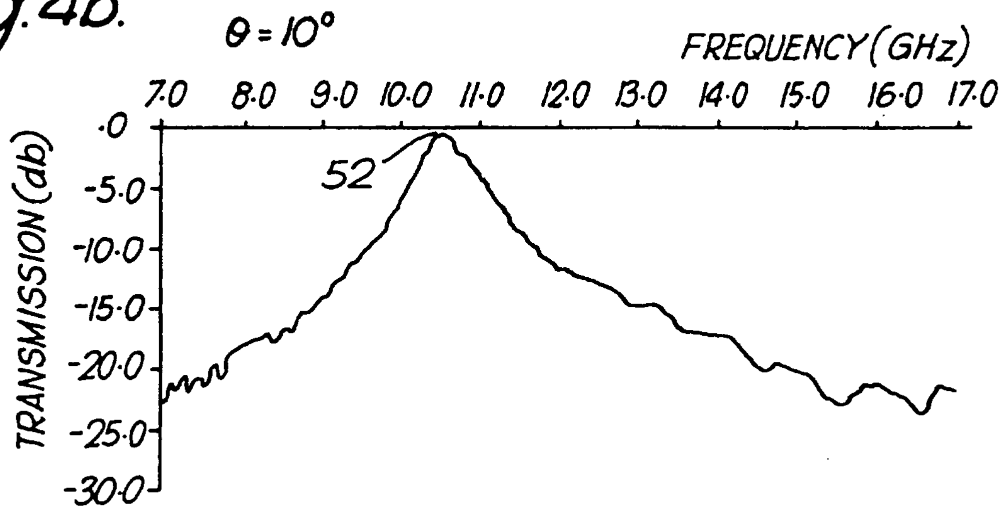


Fig. 4c.

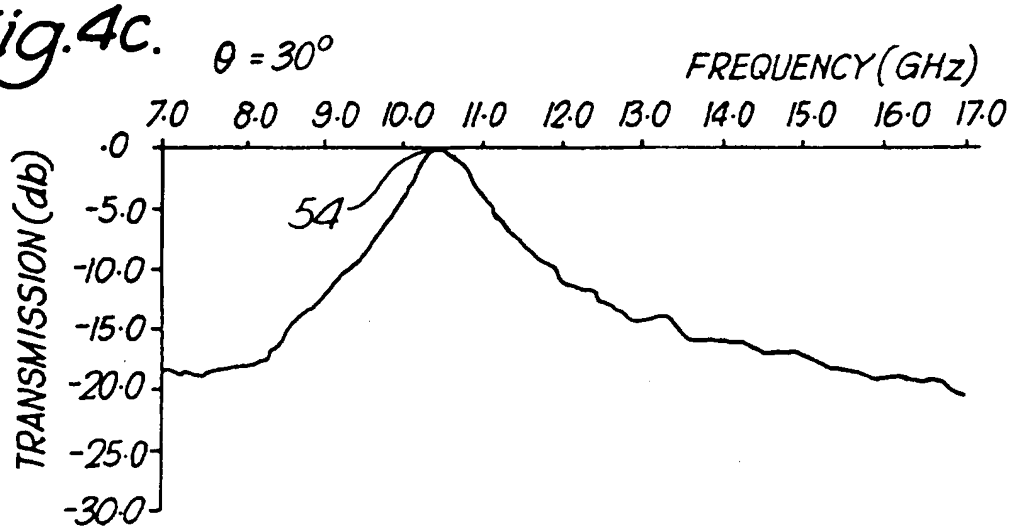


Fig.4d.

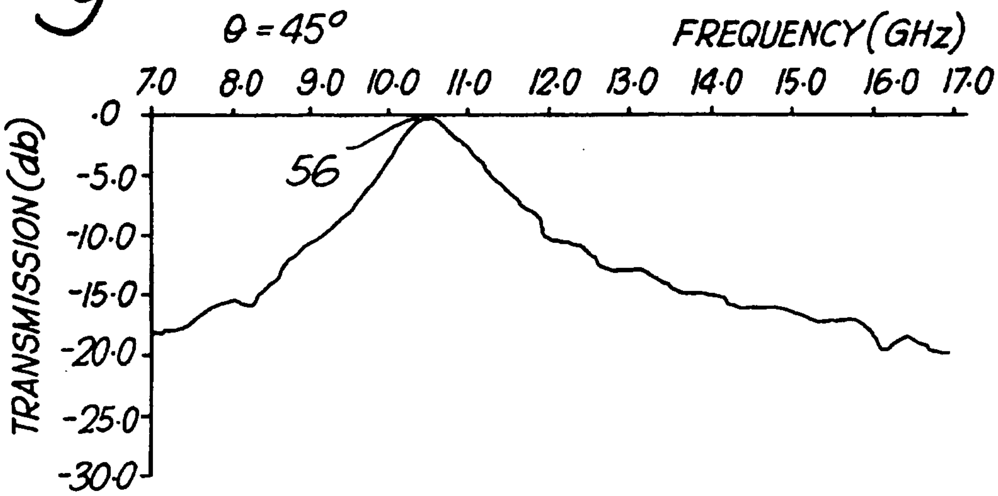


Fig.5a.

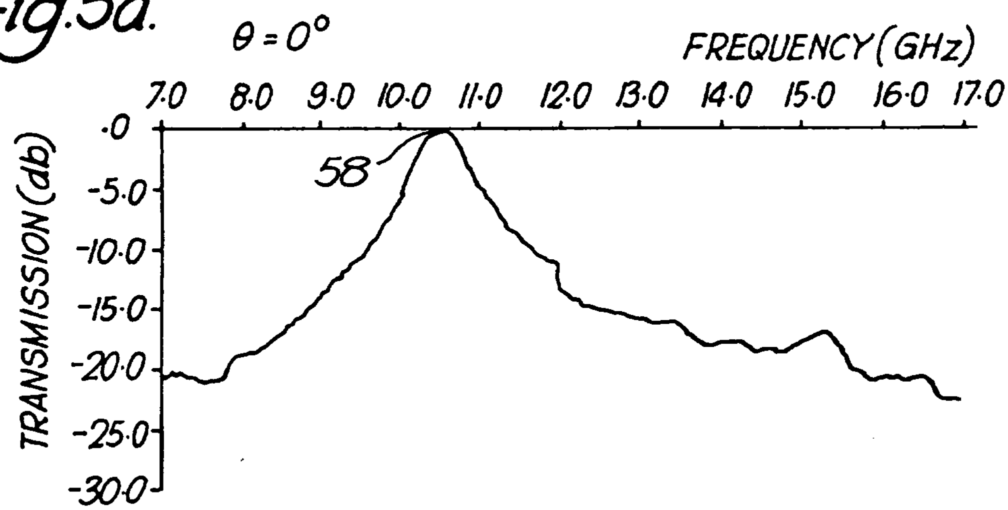


Fig.5b.

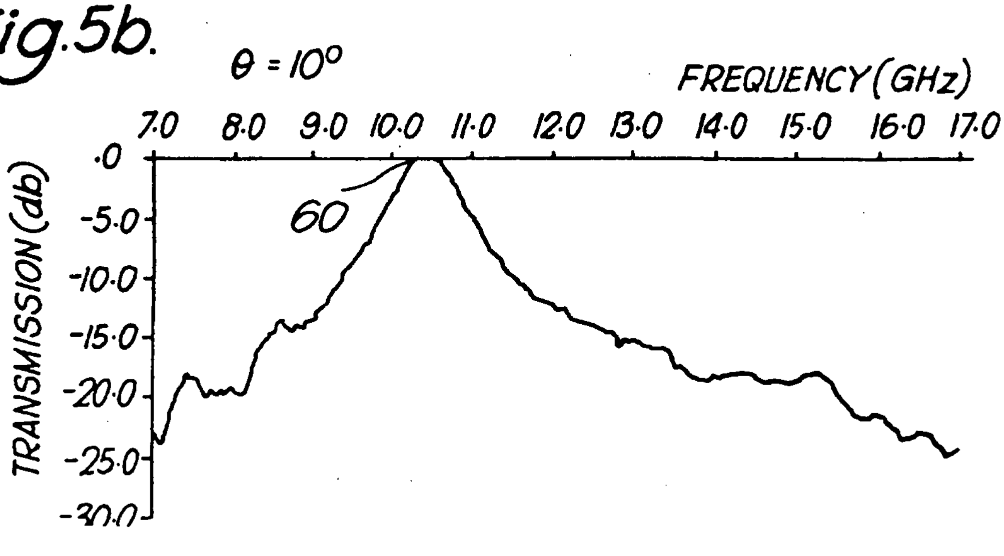


Fig.5c.

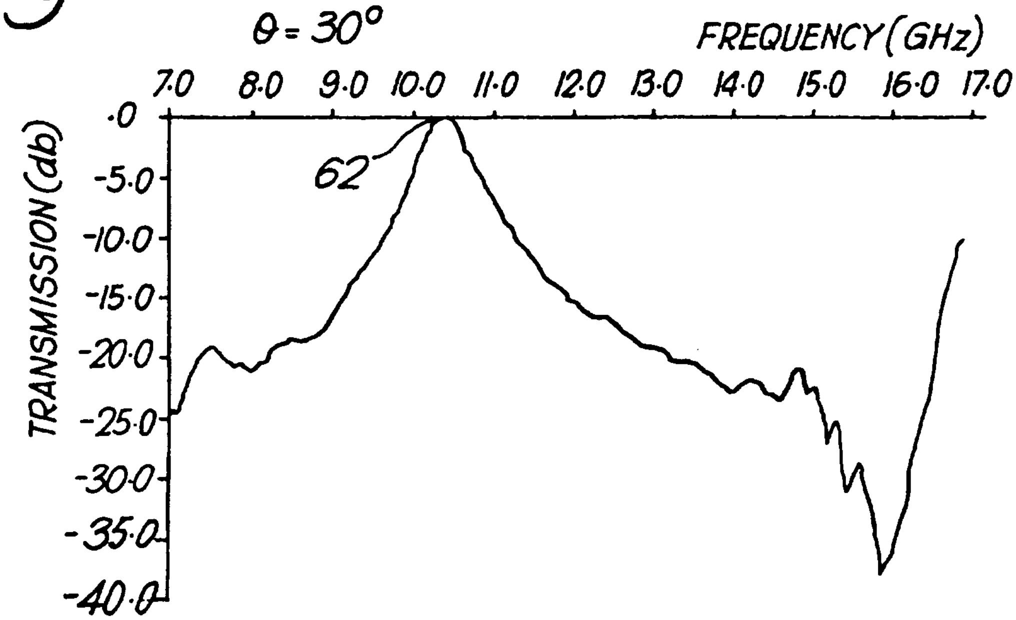

θ = 30°
FREQUENCY (GHz)
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
16.0
17.0
TRANSMISSION (db)
.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
62

Fig.5d.

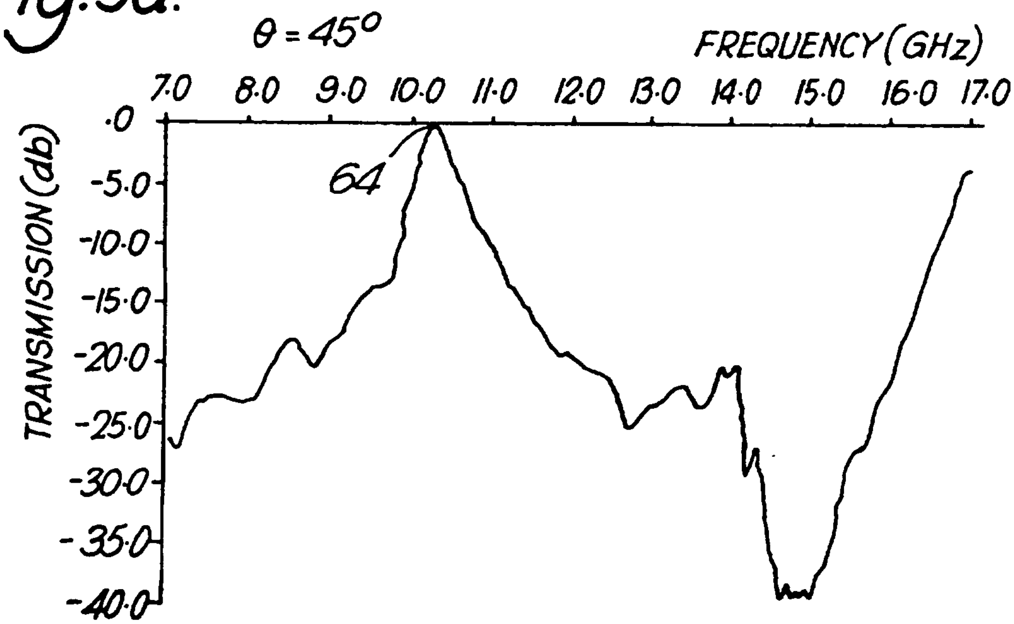

θ = 45°
FREQUENCY (GHz)
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
16.0
17.0
TRANSMISSION (db)
.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
64

Fig.6a.

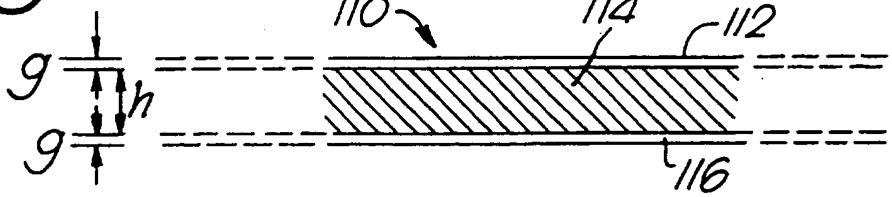


Fig.6b.

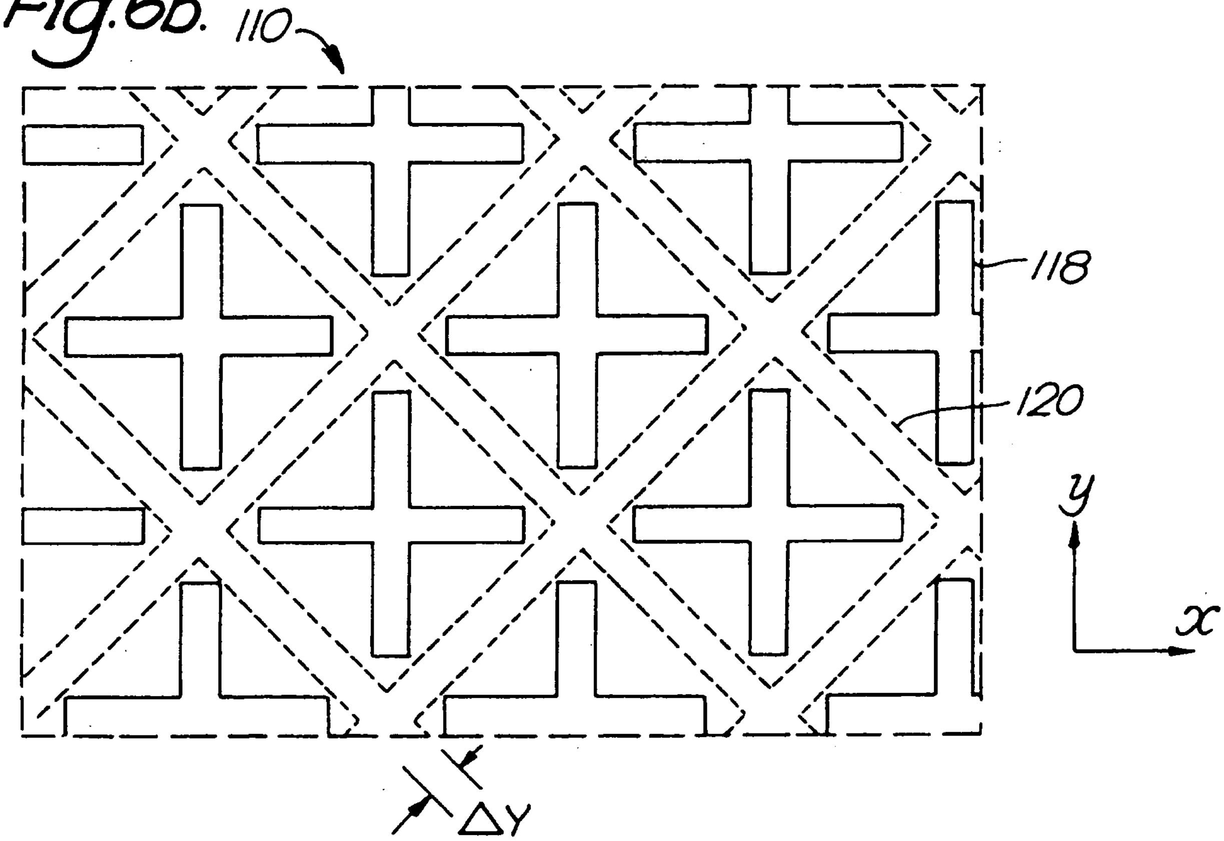


Fig.6c.

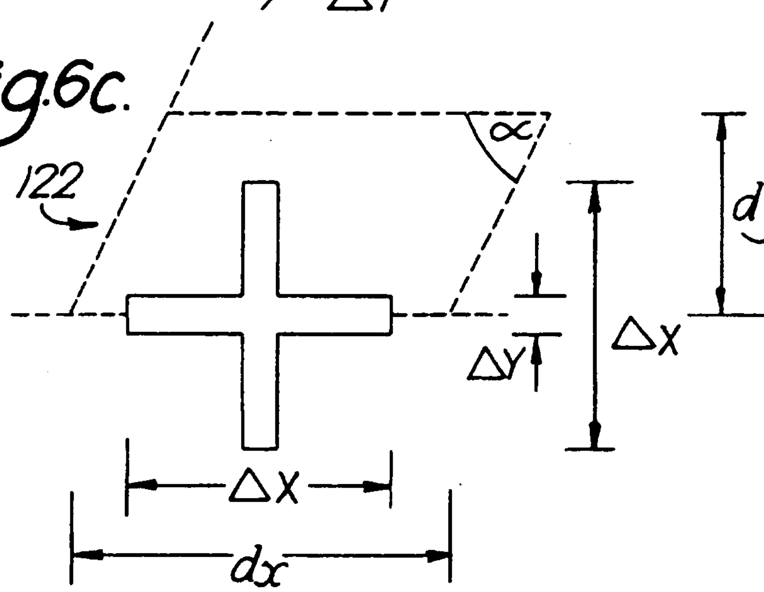


Fig.7.

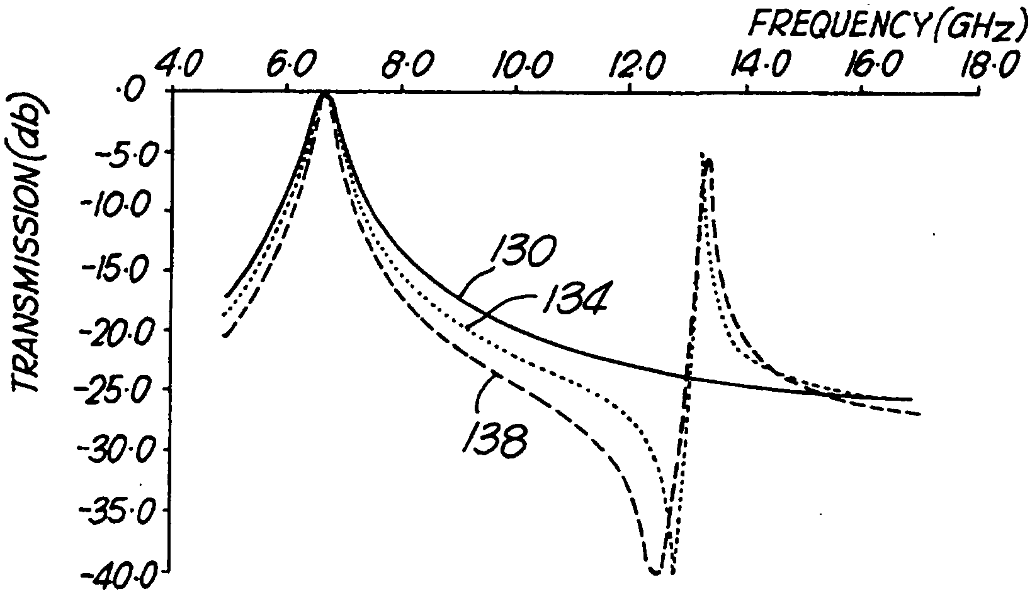
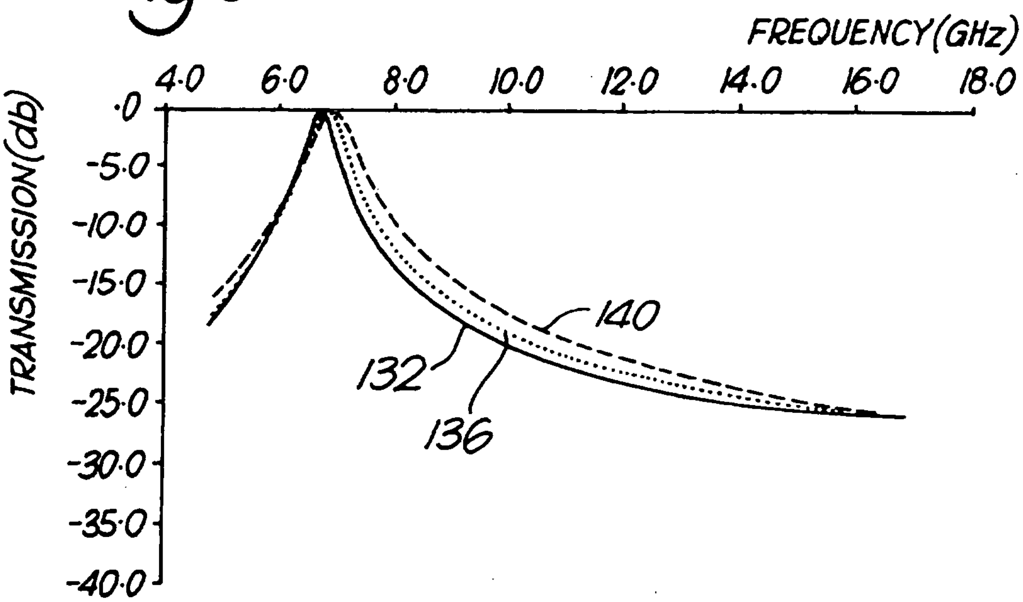

FREQUENCY(GHz)
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
TRANSMISSION(db)
·0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
130
134
138

Fig.8.


FREQUENCY(GHz)
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
TRANSMISSION(db)
·0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
140
132
136

FREQUENCY SELECTIVE STRUCTURE

The invention relates to a frequency selective structure, and more particularly to such a structure comprising two conducting layers interleaved with a dielectric layer.

Frequency selective structures (FSSs) are known in the prior art. They may be active or passive. The passive variety, at their simplest, consist of periodic arrays of conducting elements or slots in a conducting sheet. Active FSSs have periodic arrays of active elements the application of a voltage to which alters the conducting properties of the structure. Such passive and active FSSs are known for use as single conducting layers or interleaved with dielectric layers to produce multilayered structures. The dielectric layers in such multilayered structures are not less than a fifth of a wavelength thick at the operating frequency. Some examples of passive multilayered structures are discussed by R Orta, R Tascone and R Zich in IEE Proceedings, Vol. 135, Pt. H., No. 2, 1988 pages 78-82.

Prior art FSSs have reflection and transmission properties which vary with incident radiation frequency and angle of incidence. More specifically resonant frequency features shift with polarisation, and higher order resonances are dependent on angle of incidence. It has also proved difficult to tailor the bandwidth of the bandstop/bandpass characteristics of these structures.

FSSs have many applications. They may be used in multi-band antenna systems, especially those for use with satellites where multi-frequency operation in fixed frequency apertures leads to an expansion of system performance. This may lead to one satellite performing the same functions as two or three thus bringing about dramatic reductions in capital costs. Such a system is described by Kumazawa, Ueno and Ando in IEEE 1982 International Symposium Digest on Antennas and Propagation No. 12 pages 487-490. They may also be used for radioastronomy and other microwave applications where passive low noise microwave filters are required in open guided wave structures. An example of an application in the

microwave region is given by Agrawal and Imbriale in IEEE Transactions on Antennas and Propagation Vol AP-27 No. 4 July 1979 pages 466-473. They describe a design for a dichroic Cassegrain subreflector.

It is an object of the present invention to provide an alternative form of frequency selective structure.

The present invention provides a frequency selective structure of the kind incorporating two layers of conducting elements or slotted conducting sheets sandwiching a dielectric layer, the elements or slots having a unit cell periodicity,

characterised in that;

the layer of dielectric has a thickness such that evanescent waves decay by not more than 30% across the dielectric layer.

The invention provides the advantage that an FSS may be constructed with a variety of transmission characteristics and enhanced frequency stability compared to the prior art. The invention provides the further advantage that narrow bandstop/bandpass characteristics may be obtained in conjunction with frequency stability. The invention also provides the advantage that an FSS so constructed may be significantly thinner compared to the prior art, the dielectric layer being an order of magnitude or more thinner than those used in the prior art.

The invention may be arranged with an additional layer of conducting elements or a slotted conducting sheet, with an associated interleaved dielectric layer. The additional dielectric layer may have a thickness such that evanescent waves decay by no more than 30% across it.

The invention may also be arranged with a plurality of additional layers of conducting elements or slotted conducting sheets, each with an associated interleaved dielectric layer. The additional dielectric layers may each have a thickness such that evanescent waves decay by no more than

30% across them. Alternatively, some but not all of the dielectric layers may have a thickness such that evanescent waves decay by no more than 30% across each respective layer.

The invention may be arranged such that the elements or slots on adjacent conducting layers do not wholly overlap when viewed in the layer thickness direction. Alternatively, the elements or slots on adjacent conducting layers may be arranged such that they do not overlap when viewed in the layer thickness direction.

The invention may be arranged such that all or some of the dielectric layers present are of a thickness such that evanescent waves decay by no more than 20% across the respective layers.

The invention may be employed to form a cover for a microwave antenna, the FSS used being arranged to have a passband at an operating frequency of the antenna.

In order that it might be more fully understood, embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 schematically illustrates

a) a section through part of a frequency selective structure (FSS) of the invention,

b) a plan view indicating relative positions of slots in two conducting layers of the FSS of Figure 1a), and

c) a unit cell of the FSS of Figure 1a);

Figure 2 graphically illustrates the first (least decaying) evanescent wave in a dielectric layer of thickness h;

Figure 3 schematically illustrates an experimental arrangement for measuring the transmission properties of an FSS;

Figure 4 graphically illustrates the transmission properties of the FSS of Figure 1 for TM polarised radiation incident at angle θ for a) $\gamma = 0°$, b) $\gamma = 10°$, c) $\gamma = 30°$ and d) $\gamma = 45°$;

Figure 5 graphically illustrates the transmission properties of the FSS of Figure 1 for TE polarised radiation incident at angle γ for a) $\gamma = 0°$, b) $\gamma = 10°$, c) $\gamma = 30°$ and d) $\gamma = 45°$;

Figure 6 schematically illustrates

a) a section through part of an alternative embodiment of an FSS of the invention,

b) relative positions of slots in two conducting layers of the FSS of Figure 6a) and,

c) a unit cell of one conducting layer of the FSS of Figure 6a);

Figures 7&8 graphically illustrate the predicted transmission properties of the Figure 6 FSS for TM and TE polarised radiation respectively; and

Figures 9&10 are sectional views of further embodiments of FSSs of the invention.

Referring to Figure 1, three aspects of an FSS 10 of the invention are illustrated schematically. Figure 1a) shows a section through part of the FSS 10 indicating its layer structure. Figure 1b) is a plan view of the FSS 10 indicating slotted and layered construction. Figure 1c) shows a unit cell of the FSS 10. The FSS 10 incorporates a slotted conducting layer 12, a dielectric layer 14 of thickness h and a second slotted conducting layer 16. The conducting layers 12, 16 are of thickness g and have periodic patterns of slots cut through them, represented in Figure 1b) by continuous lines 18 and chain lines 20 respectively. The periodic patterns of slots can be considered as being built up of unit cells 22 as shown in Figure 1c). The slots 18, 20 are of length Δx and width Δy. The unit cells 22 are of length d_x and a second side of length $d_y/\sin \alpha$. The

slots 20 in the second conducting layer 16 are offset laterally in the y-direction by half a unit cell, ie $d_y/2$, with respect to the slots 18 in the first conducting layer 12.

In general, for the purpose of this specification, a slot is to mean a region of arbitrary shape where there is no conductor and which occupies <50% of the unit cell area $d_x d_y$.

In this embodiment the conductor is copper of thickness g = 0.034 mm. The dielectric is R T Duroid (registered trade mark) with a thickness h = 0.125 mm and a complex dielectric constant ε_r given by

$$\varepsilon_r = 2.2(1 - j\,0.0012). \qquad (1)$$

The rectangular slots 18, 22 have dimensions Δx = 10 mm and Δy= 0.666 mm, d_y = 5.0 mm and α = 41°.

The FSS 10 is designed to produce a passband at 10.5 GHz. The thickness h of the dielectric layer 14 is chosen to be of the order of $\lambda = 28.6/\sqrt{2.2} = 19.3$ mm, and the thickness h = 0.125 mm = $\lambda/154$. With the conducting layers 12, 16 separated by a dielectric layer 14 with a thickness h of this magnitude compared with a wavelength there is significant evanescent coupling of electromagnetic radiation between the conducting layers 12, 16.

Referring now to Figure 2, the propagation of evanescent waves in the layered structure 10 is illustrated graphically. Significant evanescent coupling occurs when the magnitude of the amplitude of the wave mode a distance h from the first conducting layer 12 is given by

$$|\exp(-j\gamma_{pq}h)| \sim 1 \qquad (2)$$

for values of p,q other than p = q = 0, where j is the square root of minus one, γ is the wave propagation factor, p and q are Floquet mode

indices and h is Planck's constant. At normal incidence the wave propagation factor is given by

$$\gamma_{pq} = -2\pi j\left[\left(\frac{q}{d_y} - \frac{p}{d_x \tan\alpha}\right)^2 + \left(\frac{p}{d_x}\right)^2 - \frac{\varepsilon_r\mu_r}{\lambda_o^2}\right]^{\frac{1}{2}} \qquad (3)$$

where ε_r and μ_r are the relative permittivity and permeability of the dielectric layer 14, and λ_o is the free space wavelength. In the layered structure 10 significant evanescent coupling may be taken to occur when

$$\Re e(-j\gamma_{pq}h) \geq -0.2 \qquad (4)$$

for values of p,q other than p = q = 0. That is when the evanescent waves in the dielectric layer 14 have decayed by 20% or less of their original value when incident on the second conducting layer 16. This evanescent coupling leads to improved transmission properties.

Referring now to Figure 3, an experimental arrangement 70 for the measurement of transmission properties of the FSS 10 is illustrated schematically. The arrangement 70 comprises a transmitter horn 72, an FSS panel 74, a receiver horn 76 and a vector network analyser (VNA) 78. The transmitter and receiver horns 72, 76 are of equal gain and the transmitter horn 72 produces a microwave beam 80 of width approximately 10° to the 3 dB points. The horns 72, 76 are positioned a distance L = 2.4 m on either side of the FSS 74, thus the transmitter horn 22 provides an approximate far field plane wave illumination of the FSS 74. The FSS 74 is 1.2 m square and positioned perpendicular to the direction of propagation of the microwave beam 80.

The transmitter microwave beam 80 is incident on the FSS 74 and interacts with it. Some of the beam 80 is transmitted through the FSS 74 to form a transmitted microwave beam 82. The transmitted beam 82 is received by the receiver horn 76, and its properties such as power intensity and phase are measured by the VNA 78. Measurements are also made with the FSS panel 74 removed. The transmission of the FSS panel 74 is obtained by calculating the difference of the received power vectors with and without the FSS

panel 74 in the arrangement 70. This is calculated automatically by the VNA 78.

Measurements were made over the range 7 GHz to 17 GHz. To achieve this several pairs of horns 72, 76 were used, each pair 72, 76 covering a range determined by their design.

Referring now to Figures 4 and 5 the transmission properties of the FSS 10 are illustrated graphically for incident radiation with TM polarisation and TE polarisation respectively, the radiation being incident at an angle θ and where a) θ = 0°, b) θ = 10°, c) θ = 30° and d) θ = 45°. Each graph Figure 4a) to d) and Figure 5a) to d) shows the variation of transmission intensity with frequency of incident radiation over the range 7GHz to 17GHz.

Each of the graphs Figure 4a) to d) and Figure 5a) to d) shows a respective transmission resonance or passband at approximately 10.5GHz. These features have even numbered references 50 to 64 respectively. Looking in more detail at Figure 4a) to d) there is no measurable shift, of the TM polarisation resonance frequency for θ = 0° to 45°. Measurement limits of accuracy indicate that this frequency shift must be less than 0.7%. Similarly for Figure 5a) to d) only a 2% shift of TE polarisation resonance frequency is seen for θ = 0° to 45°. This compares very favourably with equivalent measurements made on prior art devices. For example, tripole loops may be optimised to achieve similar ($\lesssim$ 2%) frequency shifts, although bandwidth control and manufacturing tolerances are difficult to achieve.

The form of the transmission resonance 50 shown in Figure 4a) will now be considered in more detail. For the transmission of TM polarisation at θ = 0°, Figure 4a) has a resonance 50 at approximately 10.5GHz with a measured 3dB bandwidth of 8 ± 1%, ie the width of the transmission maximum 50 is 8 ± 1% measured between points A and B 3dB down from the transmission maximum 50. Again this compares favourably with equivalent measurements on prior art devices. For example, where tripole loops may

typically have a 3dB bandwidth of about 20-30%. Similar improvements in 3dB bandwidth are displayed by resonances 51 to 64 shown in Figures 4b) to d) and 5a) to d).

Referring now to Figure 6 three aspects of an alternative embodiment of an FSS 110 of the invention are illustrated schematically. Figure 6a) shows a section through part of the FSS 110 indicating its layer structure. Figure 6b) shows relative positions of slots in two conducting layers. Figure 6c) shows a unit cell of the FSS 110. The FSS 110 has a first conducting layer 112, a dielectric layer 114 and a second conducting layer 116. The conducting layers 112, 116 are of copper and of thickness g = 0.034mm. The dielectric layer is of R T Duroid (registered trade mark) with dielectric constant ε_r given by equation 1, and of thickness h = 0.125mm.

The first conducting layer 112 features cross-shaped slots indicated in Figure 6b) by continuous lines 118. The second conducting layer 116 is shown underlying the first layer 112 and features a continuous grid of slots indicated by chain lines 120. The registration of the first conducting layer 112 with the second 116 is arranged such that there is no overlap of the slots 118 and 120. The cross-shaped slots 118 have slot lengths ΔX and widths ΔY as indicated in Figure 6c). The continuous grid of slots 120 are also of width ΔY.

The unit cell 122 for the first conducting layer 112 is illustrated in Figure 6c). It has a length in the x-direction d_x, a width in the y-direction d_y and an internal angle α. For the two periodic patterns of slots 118, 120 to overlay one another without slot overlap, the periods of both patterns 118, 120 must be identical. Thus the dimensions of the unit cell for the second conducting layer 116 are identical to those of the unit cell 122, although the unit cell structures differ.

In this embodiment the dimensions of the cross shaped slots 118 are ΔX = 8.000mm and ΔY = 0.500mm. The unit cell dimensions are d_x = 10.000mm, d_y = 5.000mm and α = 45°.

Referring now to Figures 7 and 8 the transmission properties of the FSS 110 for TM polarisation and TE polarisation respectively, are illustrated graphically. In these Figures continuous graphs 130, 132 represent normally incident radiation, $\theta = 0°$, dotted graphs 134, 136 represent radiation incident at $\theta = 30°$ and chain graphs 138, 140 represent radiation incident at $\theta = 45°$. Both Figures 7 and 8 show a transmission resonance, at all angles of incidence, just below 7GHz. As for the FSS 10 for TM polarisation, there is no movement of the resonance with angle of incidence θ. For TE polarisation however, there is a very small shift of the resonance to higher frequencies with increasing θ. The FSS 110 therefore provides improved stability of transmission properties with variation of polarisation and of angle of incidence θ when compared with the prior art.

The geometries of slot patterns which may be used in FSSs of the invention are not limited to those described above. For example slots may be shaped as tripoles, tripole loops, squares, concentric squares, rings, concentric rings, Jerusalem crosses, Maltese crosses and gridded structures. The slotted patterns may be identical on both conducting layers as for the FSS 10 or different as for the FSS 110, but the unit cell for both layers must have the same dimensions and internal angle α.

Alternative embodiments may also be constructed in which one or both of the slotted patterns 18, 20, 118, 120 are replaced by arrays of discrete conducting elements. Clearly the requirement for identical unit cell dimensions on both conducting layers 12, 16, 112, 116 still applies.

The embodiments 10, 110 described thus far both have slotted patterns 18, 20, 118, 120 in which the slots themselves do not overlap when viewed in plan. Alternative embodiments may be produced in which the slots or elements are 100% overlapped or partially overlapped. Such arrangements will provide different properties.

The advantages of improved stability of properties with polarisation and angle of incidence, and of sharper bandpass or bandstop characteristics

may be obtained provided the thickness h of dielectric layers 14 and 114 is small enough to produce strong evanescent wave coupling between conductors 12 and 16, 112 and 116. These properties may be observed provided the dielectric thickness h is less than $h_{max} = 0.04d$, where d is the larger of d_x and d_y. The thickness h must, however, be finite and a practical lower limit for the purposes of construction is $h_{min} = 2g$, where g is the conductor thickness.

FSSs of the invention are not limited to two conducting layers and one dielectric layer as described thus far. FSSs with additional layers may also be constructed.

Referring now to Figure 9 a section through part of a multilayer FSS 200 of the invention is illustrated indicating the layer structure. The FSS 200 has five layers. These consist of a first conducting layer 202, a first dielectric layer 204, a second conducting layer 206, a second dielectric layer 208 and a third conducting layer 210. The three conducting layers 202, 206, 210 are of thickness g. The two dielectric layers 204, 208 are of thickness h. If h is within the limits previously described there will be strong evanescent wave coupling between second and third conducting layers 206, 210. The layers themselves are as previously described.

Referring now also to Figure 10, there is shown a section through part of a seven layer FSS 300 of the invention indicating the layer structure. The FSS 300 incorporates two FSSs 310 each equivalent to the illustrated in Figure 1. They are separated by a layer 302 of low loss dielectric of thickness H, where H >> h. Therefore there is significant evanescent wave coupling between the layers 12 and 16, but not between the two FSSs 310.

Both of the multilayer approaches described may be employed to produce FSSs consisting of many more layers than have been shown. They may also be combined so that, for example, two five layer FSSs 200 may be used in place of the three layer FSSs 310 in the FSS 300.

FSSs of the invention with comparatively few layers are substantially thinner than FSSs in the prior art where dielectric layers are 100h or more thick. This is not only an advantage in itself but also facilitates their formation into curved structures as required in most applications. As with all FSSs the properties of a particular embodiment alter when the geometry changes from a flat surface to a curved one. Therefore for each application, not only must the appropriate periodic patterns of slots and/or elements be chosen but the geometry of the final structure must be taken into account.

FSSs of the invention have a wide range of applications. One such application is their use in the construction of radomes for microwave antennas. Such radomes may be constructed from a plurality of flat sheets of FSS thus forming a multi-faceted surface. Alternatively the FSS may be shaped to produce a radome with a continuous curved surface. The FSS is designed to have a passband such that the antenna operating frequency is transmitted whilst other frequencies are attenuated.

CLAIMS

1. A frequency selective structure of the kind incorporating two layers of conducting elements or slotted conducting sheets sandwiching a dielectric layer, the elements or slots having a unit cell periodicity,

characterised in that;

the layer of dielectric has a thickness such that evanescent waves decay by not more that 30% across the dielectric layer.

2. A frequency selective structure according to claim 1 incorporating an additional layer of conducting elements or an additional slotted conducting sheet and with an associated interleaved dielectric layer, the elements or slots having a unit cell periodicity, and the additional dielectric layer having a thickness such that evanescent waves decay by not more than 30% across it.

3. A frequency selective structure according to claim 1 incorporating a plurality of additional layers of conducting elements or slotted conducting sheets each with an associated interleaved dielectric layer, the elements or slots having a unit cell periodicity, and the additional dielectric layers having thicknesses such that evanescent waves decay by not more than 30% across each respective layer.

4. A frequency selective structure according to claim 1 incorporating a plurality of additional layers of conducting elements or slotted conducting sheets each with an associated interleaved dielectric layer, the elements or slots having unit cell periodicity, and some but not all of the additional dielectric layers having thicknesses such that evanescent waves decay by not more than 30% across each of them.

5. A frequency selective structure according to any one of the preceding claims in which the elements or slots on adjacent conducting layers do not wholly overlap when viewed in the layer thickness direction.

6. A frequency selective structure according to claim 5 in which the elements or slots on adjacent conducting layers do not overlap when viewed in the layer thickness direction.

7. A frequency selective structure according to claim 1, 2 or 3 wherein each dielectric layer has a thickness such that evanescent waves decay by no more than 20% across it.

8. A frequency selective structure according to claim 4 wherein some but not all of the dielectric layers have thickness such that evanescent waves decay by not more than 20% across each respective layer.

9. A frequency selective structure according to any one of the preceding claims formed into a cover for an antenna and arranged to have a passband at a frequency of operation of the antenna.

Patents Act 1977

Examiner's report to the Comptroller under Section 17 (The Search Report)

Application number

Relevant Technical fields

(i) UK Cl (Edition K) H1Q (QEC, QEJ, QEX, QKJ)

(ii) Int Cl (Edition 5) H01Q

Databases (see over)

(i) UK Patent Office

(ii)

Search Examiner

J BETTS

Date of Search

13 December 1991

Documents considered relevant following a search in respect of claims 1-9

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
	NONE	all